Nitrogen Contribution from Red Clover for Corn Following Wheat in Western Ohio

Thesis

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By

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Abstract

Inclusion of a winter legume cover crop into a crop rotation has been suggested as a method to provide a substantial portion of the nitrogen (N) requirement of a subsequent grass crop. While the benefits of winter cover crops such as reduced soil erosion, increased soil organic matter, and increased mulch cover have been well documented, the N contribution to the subsequent crop has shown to be variable. The objective of this study is to determine the N contribution from a red clover (*Trifolium pretense*, L.) cover crop following wheat (*Triticum aestivum*, L.) to a subsequent corn (*Zea mays*, L.) crop. The experiment was conducted at two western Ohio locations over three years. At both locations, red clover was either interseeded into wheat or seeded after harvest, the red clover cover crop was eliminated with tillage or herbicide application, and corn was planted with three N rates (0, 90, and 180 kg N ha⁻¹). The data revealed that for three of the four site years (when the cover crop was successfully established) there was no N contribution attributable to the presence of red clover. The one site that did show an N contribution revealed that the amount of N contributed was less than 90 kg N ha⁻¹. However, even when no N benefit was found, yields were improved by non-N related rotational effects. Significant reductions in N fertilization rates following a red clover cover crop are likely to result in lost corn yield opportunities in western Ohio.

Dedication

Dedicated to my family and friends who have supported me through all of my academic adventures.

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I would like to sincerely thank my advisor, Robert Mullen, for his advice, patience, and understanding throughout my graduate career and my committee members Nicholas Basta and Charles Goebel for their time and consideration.

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Many thanks to the OARDC farm staff for their help with our projects and helping me get the truck out of the mud hole on West Badger.

Vita

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Publications

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Fields of Study

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Nitrogen Contribution from Red Clover for Corn Following Wheat in Western Ohio

Introduction

Application of nitrogen (N) fertilizers to cropland is a considerable portion of the cost and energy input associated with non-legume crop production (Oyer and Touchton, 1990). When N is lost from cropland, it represents both a financial loss to producers and a potentially negative impact to the environment. Legume cover cropping has been proposed as a method to reduce input costs by supplementing N and reducing environmental risks by reducing N losses (Reinbott et al., 2004). Incorporation of legume cover crops into a crop rotation may provide advantages over non-legume cover crops (Ebelhar et al., 1984).

Benefits of using legume cover crops are a reduction of soil loss through wind and water erosion, an increase soil organic matter, and cover crops take up excess plant available N that may otherwise be lost through leaching, denitrification, or volatilization (NRCS, 2008). Meta-analysis of legume cover crops in Canada and the U.S. has shown an overall positive effect on corn (*Zea mays* L.) yield (Miguez and Bollero, 2005). When soil N is low, legume cover crops may supplement N through fixation of atmospheric nitrogen increasing subsequent corn grain yields (Blevins et al., 1990). Inclusion of legume cover crops also provide yield benefits from other soil property enhancements such as improved infiltration, increased mulch cover, and soil moisture conservation

(Corak et al., 1991; Ebelhar et al., 1984; Sarrantonio and Scott, 1988; Stute and Posner, 1995; Utomo et al., 1990).

As with any agricultural practice that has a cost associated with it, there is an inherent risk for financial loss. De Bruin et al. (2005) found that inclusion of a rye cover crop, while producing comparable yields to a fallow treatment, reduced economic returns for corn production. Soil and weather conditions after crop harvest, prior to cover crop seeding, may inhibit cover crop establishment (Eckert, 1988). If establishment is successful, winter precipitation has a significant effect on the biomass production and N accumulation of cover crops (Kuo and Jellum, 2000). Weather conditions during the following growing season may also limit microbial activity slowing nitrogen mineralization from cover crop residues (Wagger, 1989). Utomo et al. (1990) have suggested that the use of conventional tillage to eliminate cover crops increases mineralization of N to the subsequent corn crop. Bruulsema and Christie (1987) refer to this mineralization increase at plowdown as a “priming” effect. In no-till systems, cover crops must be eliminated with herbicides and that represents additional costs to the producer. Interseeding of legumes has shown not to affect soybean yields, but cover crop establishment can be difficult (Hively and Cox, 2001). Additional input cost to manage cover crops, may not be fully recovered by subsequent crop yields. The shorter growing seasons in northern latitudes make establishment of cover crops after a summer row crop difficult.

The objective of this research was to quantify the N contribution from a red clover (*Trifolium pretense* L.) cover crop established within or after winter wheat (*Triticum aestivum* L.) prior to corn (*Zea mays*, L.) planting. Rotational effects are non-N related

factors that produce increased yields in subsequent crops (Andraski and Bundy, 2005). These effects can be misinterpreted as N contribution if inappropriate comparisons are made in the absence of N rates. Reducing N applications based on that misinterpretation may lead to limited N supply to a following non-legume crop that can represent loss of yield opportunity. Soil tests for N do not show what N may become plant available as cover crop residues decompose (Kuo and Jellum, 2000). Performance of subsequent crop is likely the best way to determine cover crop benefits. In order to determine whether increased yields following a cover crop are due to rotational effects or N contribution, a range of nitrogen rates, including a check (0 N), need to be applied to a non-legume crop when following a cover crop compared with no cover crop. The relationship between the N response curves will determine whether there is an N contribution.

Materials and Methods

The experiment was conducted at two locations in western Ohio, the OARDC Western Research Station near South Charleston, OH (39°51'33" N, 83°40'17" W) and the OARDC Northwest Research Station near Custar, OH (41°13'05" N, 83°45'38" W). Experimental methods at each location differed slightly to better represent agricultural practices used in the respective areas. Initial soil samples were collected in the spring prior to corn planting, and the initial soil test information for each location is reported in Table 1.

At both locations, the experimental design was a split plot in a randomized complete block design with a main plot effect of cover and subplot effects of N rate with four replications. Analysis of variance to determine main plot, subplot, and interaction effects was done using GLM and MIXED in SAS (SAS Inc., 2004). Optimum sidedress N rates were determined using NLIN in SAS to identify a quadratic response function and setting the first derivative of the quadratic model equal to zero.

Western Research Station

The experiment was initially established in mid-July 2005 on a Crosby silt loam (fine, mixed, mesic Aeric Ochraqualf). Red clover was drilled following wheat harvest at a rate of 11 kg ha⁻¹. Dry soil conditions due to higher than average wheat yields and low summer rainfall amounts prevented red clover establishment, and the experiment was delayed until July 2006. Red clover was again seeded at a rate of 11 kg ha⁻¹ following wheat harvest. In April of 2007, biomass samples were collected from all main plots that

contained red clover prior to stand termination (Table 2). Red clover stands were terminated with either incorporation by chisel and disk tillage or by herbicide application consisting of 0.9 kg ha⁻¹ ae glyphosate [*N*-(phosphonomethyl)glycine] tankmixed with 0.44 L ha⁻¹ dicamba (3,6-dichloro-2-methoxybenzoic acid). Tilled plots were also tilled with a field cultivator prior to seeding for seedbed preparation. Corn ('Pioneer 34A18') was planted on May 5, 2007 at a seeding rate of 79 000 seeds ha⁻¹. Prior to sidedressing, presidedress soil nitrate tests (PSNT) were collected from each of the main plots (June 1, 2007 and June 2, 2008). Eight soil cores were collected to a depth of 30 cm to constitute a composite for each main plot. Corn was sidedressed with UAN by coulter-injection at V4 (Ritchie et al., 1997). Sidedress nitrogen rates were 0, 90, and 179 kg N ha⁻¹. Each plot was 3.0 m (four 0.76 m rows) by 12.2 m. Final stand counts were made prior to corn harvest by counting harvestable ears from the two center rows by 5.3 m. Corn yields were determined from harvesting the two center rows and adjusted at harvest using a self-propelled small-plot combine. The same experiment was carried out after wheat harvest in April 2008 and 2009 on different experiment blocks at the research station.

Northwest Research Station

In April 2005, red clover was interseeded into a standing wheat crop at a rate of 11 kg ha⁻¹ on a Hoytville clay (fine, illitic, mesic Mollic Epiaqualf). Dry weather conditions and higher than average wheat yields prevented cover crop establishment at this location similar to those reported for the Western Research Station. Red clover was again interseeded into an established wheat stand in April 2006. Wheat was harvested in June 2006. Red clover stands were sampled for biomass (Table 2) and terminated in late October 2006. Red clover was terminated by either incorporation with chisel/disk tillage

or herbicide application consisting of 0.9 kg ha⁻¹ ae glyphosate tankmixed with 0.44 L ha⁻¹ dicamba. Tilled plots were also tilled with a field cultivator in the spring for seedbed preparation. In April 2007, corn hybrid ‘Pioneer 34A18’ was planted with a starter N at a rate of 14 kg ha⁻¹. No starter was applied to the check (0 N) treatments. Presidedress soil nitrate soil tests were collected prior to sidedressing (May 29, 2007 and June 17, 2008) employing the same methodologies described for the Western Research Station. Additional N was applied at V4 by coulter-injection at rates of 0, 76, and 165 kg ha⁻¹. Each plot was 3.0 m (four 0.76 m rows) by 22.9 m. Grain yields were determined from harvesting the two center rows using a self-propelled small-plot combine and adjusted to 15.5% moisture. The same experiment was carried out beginning April 2008 and 2009 at different experiment blocks located on the research station with the corn hybrid ‘Pioneer 34M78.’

Results

Northwest Research Station 2007

At this site there was no significant interaction of N rate by cover crop treatment on corn yield, final stand, or grain moisture thus only main effects will be discussed. Red clover cover crop treatments produced increased corn yields as compared to the no cover treatment (Table 3). The no cover treatment produced 6190 kg ha^{-1} while the no-till red clover and tilled red clover treatments yielded 7320 and 7766 kg ha^{-1} , respectively. There was also a significant effect of tillage on corn grain yield with tillage providing a 446 kg ha^{-1} increase over corn established with no-till. Final stands were also affected by cover crop treatment (Table 3). Dry weather late during the growing season resulted in aborted ears that were not harvestable and that accounts for the relatively low final stands for all treatments. A tillage effect was noted as the plots that received fall tillage had higher plant stands than the no-till plots. This could partially account for yield increases associated with the red clover tillage treatment. Grain moisture measured at harvest revealed the same tillage effect (Table 3). Each incremental increase in N rate produced significantly greater corn grain yields of 4509 , 8131 , and 8636 kg/ha at the 0 , 90 , and 179 kg N ha^{-1} rates, respectively (Table 4). Red clover cover crop treatment had no effect on PSNT level (Table 9).

Based upon the lack of an interaction and similar optimum N rates for the different cover crop treatments (including the no cover crop treatment) (Fig. 1), there was

not a nitrogen contribution detected from the presence of the red clover cover crop.

Yields at the 0 N rate were significantly higher when a cover crop was present, but actual response to N was similar for all main plot treatments. Comparing the yields of control plots (0 N) can lead to an incorrect conclusion that there was a significant N contribution (Bollero and Bullock, 1994). We hypothesize that the presence of the red clover cover crop resulted in a rotation benefit that was to the advantage of the subsequent corn crop. It should be noted that the average grain yield at this experiment location is 11 300 kg ha⁻¹.¹ Rainfall during this growing season was low during the final two months, and that resulted in decreased yields. Despite the difficult growing conditions for this site-year, significant yield increases were observed when red clover used as a cover crop.

Northwest Research Station 2008

Analysis of this site-year revealed an interaction between the N rate and cover treatments, so simple effects will be discussed. This interaction is explained by a significant increase in corn grain yield at the 90 kg ha⁻¹ N rate when both the red clover no-till and the red clover tilled treatments were used (Table 5). At the 0 and 180 kg ha⁻¹ N rates, no difference in yield was found among cover crop treatments. Within each cover treatment, corn grain yields significantly increased with each increase in N rate treatment. Tillage had no effect on corn yields at any of the N rates. Final stands were not affected by either the cover crop treatment or the N rates evaluated (data not shown). Both red clover treatments increased PSNT compared to the no cover treatment by 0.8 mg kg⁻¹ in the no-till and 0.7 mg kg⁻¹ in the tilled (Table 12).

Calculation of the optimum N rate for the different cover crops is impossible because maximum yield is not achieved with the N rates evaluated (Table 5). Despite that fact, the 0 N control revealed no additional yield advantage associated with the presence of a cover crop, so by that definition there was no N contribution attributable to the presence of the red clover cover crop. What is of note is the yield increase associated with the presence of the cover crop at the 90 kg N ha⁻¹ rate. This likely reveals an improvement in N use efficiency due to the presence of the cover crop and perhaps some slight rotational benefit. This benefit was not observed at the 180 kg N ha⁻¹ rate.

Northwest Research Station 2009

At this site there was no interaction of N rate by cover crop treatment on corn yield. Thus, only main effects will be discussed. The red clover tilled treatment increased corn yields as compared to the no cover treatment (Table 6), but the red clover no-till treatment was not significantly different than either the no cover or red clover tilled treatments. The no cover treatment produced 5807 kg ha⁻¹ while the no-till red clover and tilled red clover treatments yielded 6325 and 6879 kg ha⁻¹, respectively. A relatively wet and cool growing season resulted in low yields for all treatments (the location average was 6337 kg ha⁻¹) likely due to denitrification early in the growing season and heavy pathogen pressure. There was no tillage effect noted on corn grain yield, but a minimal decrease in grain moisture at harvest was detected in plots receiving tillage (Table 6). Each incremental increase in N rate produced significantly greater corn grain yields of 3224, 6846, and 8942 kg/ha at the 0, 90, and 180 kg N ha⁻¹ rates,

respectively (Table 7). Red clover cover crop treatment had no effect on PSNT level (Table 12).

Calculation of the optimum N rate for the different cover crops is impossible because maximum yield was not achieved with the N rates evaluated. Despite that fact, the 0 N control revealed a yield advantage associated with the presence of a cover crop of approximately 600 kg ha⁻¹. There was also a yield advantage at the 90 and 180 kg N ha⁻¹ rate, but to a lesser extent. The yield gain attributed to the cover crop may be a result many factors including some nitrogen contribution, this contribution however, cannot be quantified due to the lack of optimum nitrogen rates. It should be noted for this site, that even though no effect of repetition was found, results from this site were quite variable due to the poor growing conditions resulting from excessive moisture, especially early in the growing season.

Western Research Station 2007

Only main effects are presented and discussed for this site due to the lack of interaction of N rate by cover crop treatment on corn yield (Table 8). The no cover and red clover no-till treatments showed no differences in corn yield. Similarly, there was no difference in grain yield between the no cover and red clover tilled treatments. There was a negative tillage effect shown by a significant decrease in corn yield when tillage was used (Table 8). There was no difference in yield between the 0 and 90 kg ha⁻¹ N rates, 10 131 and 10 554 kg ha⁻¹ respectively. The 180 kg ha⁻¹ N rate corn yield was significantly greater at 11 972 kg ha⁻¹ (Table 9). Cover crop treatment had no effect on PSNT (Table 12) and final stands were not affected by cover crop treatment (data not shown).

The lack of interaction between N rate and cover treatment indicates that there was no nitrogen contribution from the clover cover crop. There was also minimal response to N rate, only the 180 kg ha⁻¹ N rate showed a slight yield increase (Table 9). The minimal N response was likely due to initial soil nitrate levels that were already very high as shown by PSNT (Table 12). Dry weather during the late summer of 2007 may also explain the lack of N rate response with corn yields for the whole experiment only averaging 10 800 kg ha⁻¹.

Western Research Station 2008

Only simple effects will be discussed due to the finding of an interaction between the cover crop and N rate treatments. This interaction was due to a significant increase in corn yield for both red clover treatments at the 0 kg ha⁻¹ N rate (Table 10). Both red clover treatments had corn yields of 5 919 and 6 081 kg ha⁻¹ for the no-till and tilled respectively, more than double the no cover treatment with 2 616 kg ha⁻¹. Cover crop treatment had no effect on corn yields at either the 90 or 180 kg ha⁻¹. Tillage had no significant effects on corn yields in any of the cover treatments. The red clover tilled treatment had a significantly greater PSNT than the no cover treatment, but the red clover no-till was not significantly different from either. Cover crop treatment had no effect on final stand (data not shown). The presence of a cover crop did increase soil nitrate levels measured prior to sidedressing, but the increases were minimal (Table 12).

An N contribution is suspected at this site due to the increased yields of both red clover treatments at the 0 N rate. This yield increase is suspected to be the result of an N contribution and not a rotational effect because there were no corn yield differences at the

90 and 180 N rates. The amount of N contributed by the red clover is difficult to quantify. The corn yields were extremely variable as evidenced by the LSD values (Table 10). Agronomic optimum N rates for the no cover, red clover tilled, and red clover no-till were approximately 160, 180, and 140 kg ha⁻¹, respectively. Comparison of agronomic optimum N rates indicates a 20 kg ha⁻¹ benefit between the no cover and red clover no-till treatments, but a 20 kg ha⁻¹ loss between the no cover and red clover tilled treatments. Ignoring the quadratic model and simply evaluating the means and statistical differences, it would appear that significantly less than 90 kg N ha⁻¹ was provided by the red clover cover crop since the 0 N no cover treatment yielded significantly less than the red clover treatments, but the yield difference was made up with only 90 kg N ha⁻¹ supplied.

Western Research Station 2009

Only simple effects will be discussed due to the finding of an interaction between the cover crop and N rate treatments. This interaction was due to a significant increase in corn yield for the red clover tilled treatment at the 90 and 180 kg ha⁻¹ N rate as compared to the red clover no-till and no cover treatments (Table 11). The red clover tilled treatment had a corn yield of 13 142 and 14 834 kg ha⁻¹ for the 90 and 180 kg ha⁻¹ respectively, as compared to the no cover and red clover no-till treatments with yields of 11 532 and 13 773 kg ha⁻¹ and 12 683 and 13 454 kg ha⁻¹, respectively. Cover crop treatment had no effect on corn yields at the 180 kg ha⁻¹ when tillage was not used to terminate the cover crop. The red clover tilled treatment had a significantly greater PSNT than the no cover treatment, but the red clover no-till was not significantly different than

either (Table 12). The red clover no-till treatment resulted in a slight decrease in stand as compared to the no cover treatment (data not shown).

An N contribution is suspected at this site due to the increased yields of the red clover tilled treatments at the 0 N rate. This yield increase is suspected to be partially the result of an N contribution in combination with a rotational effect because there were also corn yield differences at the 90 kg N ha⁻¹ rate but not the 180 kg N ha⁻¹ rate (Table 11). The amount of N contributed by the red clover is difficult to quantify and in this case is not possible. An agronomic optimum N rate could only be calculated for the red clover no-till and was approximately 150 kg ha⁻¹, the other two treatments did not receive a sufficient nitrogen supplement to maximize yields. Comparison of agronomic optimum N rates is the only method to correctly estimate nitrogen contribution to the corn crop. The data suggests that using tillage to terminate the red clover resulted in a lower agronomic optimum N rate than using herbicide or no cover crop at this location.

Discussion

This experiment differs from other research projects in the way that N contribution is determined. Oyer and Touchton (1990) promoted the use of a fertilizer nitrogen equivalent calculation whereby the control (0 N) of the no cover treatment would be replaced by the control (0 N) of a cover crop treatment. Several other researchers employed the fertilizer equivalency method or similar methods for determining the N contribution of a cover crop as well (Reinbott et al., 2004; Stute and Posner, 1995). Others have not utilized N rates as a factor in the experiment to determine N contribution of legume cover crops (Bruulsema and Christie, 1997). These approaches do not allow for the separation of non-N effects from N effects potentially inflating the estimated N contribution from the cover crop (Bollero and Bullock, 1994). With the known non-N benefits of legume cover crops to subsequent crops (Sarrantonio and Scott, 1988; Corak et al., 1991; Bruulsema and Christie, 1997). Research should be designed to differentiate non-N benefits from N benefits to allow producers and decision makers the opportunity to capitalize on an economic opportunity in the form of increased yield. Red clover cover crops grown in Ohio may represent a yield increase opportunity, but dramatically decreasing N rates with the assumption that a significant amount of N has been fixed and potentially available may detract from that opportunity.

When assessing the N contribution for legume cover crops, not only should the analytical method of determining N contribution be considered, but the geographic location in which the experiment was performed. Soil temperature and moisture

conditions have a dramatic effect on the rate of residue decomposition and subsequent N mineralization (Quemada and Cabrera, 1996). Douglas and Rickman (1992) were able to build accurate models for crop residue decomposition at a wide range of climates. In temperate climates such as Western Ohio, soils may remain frozen for several months in which no growth or decomposition occurs decreasing N accumulation and delaying N release. Decreases in N accumulation due to lack of growth decreases the potential N contribution from a legume cover crop, and delays in N release due to cool spring temperatures decrease the N supplying ability of legume cover crops. Cover crops grown in warmer, southern latitudes are more likely to show N contributions due to greater cover crop growth during winter months and more rapid turnover of residues returned to the soil in the subsequent crop year.

Conclusions

Based upon this study, a red clover cover crop established during or after a wheat crop does not appear to be a reliable method of supplementing N for a subsequent corn crop in western Ohio. In only one out of six site-years (if the failed cover crops of 2006 are not considered) was a significant N contribution detected. Red clover was well established in the final three years of the study at each location, but the N captured in the cover crop biomass apparently did not mineralize and become available to the subsequent cover crop. One possible explanation for the lack of residue breakdown and subsequent mineralization are the cool growing seasons typical of northern latitudes. Soil temperatures are simply not high enough to promote rapid turnover of the cover crop residue to supplement corn N demand. Despite the lack of inconsistent N contribution from the cover crop, yield increases associated with the presence of red clover were noted in three out of six site-years. Potential additional benefits of cover crops such as decreased inorganic N susceptible to loss after wheat harvest, increases in soil organic matter, or other soil chemical or physical changes were not measured.

Additionally, use of PSNT does not appear to be a reliable method of ascertaining the amount of N that will be supplemented by a red clover cover crop in western Ohio. Again, this is likely due to relatively cool soil temperatures in late May when sidedressing typically occurs and the lack of residue degradation. Soil microbiological activity has simply not had enough time to mineralize the organic N to a plant available form.

Table 1. Initial soil test information at each experimental site.

Location	Soil pH ^a	Available P ^b	Exchangeable K ^c	CEC	Organic matter ^d
		-----mg kg ⁻¹ -----		meq (100 g) ⁻¹	%
Northwest 2007	6.2	22	238	23.8	4.6
Northwest 2008	5.9	45	245	21.5	4.0
Northwest 2009	6.7	22	220	20.0	3.9
Western 2007	6.1	15	147	17.4	4.8
Western 2008	6.8	13	96	11.0	2.5
Western 2009	5.8	36	135	26.5	4.0

a - soil pH measured with 1:1 soil:water; b – available P measured with Bray-Kurtz-P-1;
c - exchangeable K measured with 1 N ammonium acetate; organic matter measured
with loss on ignition

Table 2. Red clover biomass measured prior to stand termination at each experimental site (if measured).

Location	Biomass, kg ha ⁻¹	N concentration, %	N uptake, kg ha ⁻¹
Northwest Fall 2007	4,500	---	---
Northwest Fall 2008	2,900	---	---
Western Spring 2008	3,400	3.0	102
Western Spring 2009	3,700	---	---

Table 3. Main effect of cover crop on corn grain yield at the Northwest Research Station in 2007.

Cover crop	Yield, kg ha ⁻¹	Stand, ears ha ⁻¹	Moisture, %
No cover	6,190	49,000	22.2
Red clover no-till	7,320	42,100	22.4
Red clover tilled	7,766	37,000	20.7
LSD _{0.05}	303	6,300	0.8

Table 4. Main effect of nitrogen rate on corn grain yield at the Northwest Research Station in 2007.

Nitrogen rate, kg/ha	Yield, kg ha ⁻¹	Stand, ears ha ⁻¹	Moisture, %
0	4,509	39,900	22.0
90	8,131	45,100	21.3
180	8,636	43,200	21.9
LSD _{0.05}	285	NS	NS

Table 5. Effect of red clover cover crop on soil nitrate levels measured prior to sidedress N application at both locations, 2007-2009.

Cover crop	Location					
	Northwest 2007	Northwest 2008	Northwest 2009	Western 2007	Western 2008	Western 2009
	-----Nitrate level, mg kg ⁻¹ -----					
No cover	7.3	3.9	7.5	22.2	5.1	9.6
Red clover no-till	7.8	4.7	8.1	21.3	6.2	12.0
Red clover tilled	7.8	4.6	9.3	16.6	7.2	14.4
LSD _{0.05}	NS	0.5	NS	NS	0.9	2.6

Table 6. Simple effects of cover crop and nitrogen rate on corn grain yield at the Northwest Research Station in 2008.

Cover crop	Nitrogen rate, kg ha ⁻¹	Yield, kg ha ⁻¹
No cover	0	1,817
	90	5,303
	180	7,260
Red clover no-till	0	1,896
	90	6,000
	180	7,867
Red clover till	0	2,498
	90	6,246
	180	7,435
Nitrogen rate means within same cover LSD _{0.05}		584
Nitrogen rate means for different covers LSD _{0.05}		694

Table 7. Main effect of cover crop on corn grain yield and moisture at the Northwest Research Station in 2009.

Cover crop	Yield, kg ha ⁻¹	Moisture, %
No cover	5,807	26.0
Red clover no-till	6,325	26.2
Red clover tilled	6,879	24.9
LSD _{0.05}	594	1.3

Table 8. Main effect of nitrogen rate on corn grain yield at the Northwest Research Station in 2009.

Nitrogen rate, kg/ha	Yield, kg ha ⁻¹	Moisture, %
0	3,224	27.1
90	6,846	25.1
180	8,942	24.8
LSD _{0.05}	288	1.0

Table 9. Main effect of cover crop on corn grain yield at the Western Research Station in 2007.

Cover crop	Yield, kg ha ⁻¹
No cover	11,057
Red clover no-till	11,751
Red clover tilled	9,638
LSD _{0.05}	1,453

Table 10 Main effect of nitrogen rate on corn grain yield at the Western Research Station in 2007.

Nitrogen rate, kg/ha	Yield, kg ha ⁻¹
0	10,131
90	10,554
180	11,972
LSD _{0.05}	1,189

Table 11. Simple effects cover crop and nitrogen rate on corn grain yield at the Western Research Station in 2008.

Cover crop	Nitrogen rate, kg ha ⁻¹	Yield, kg ha ⁻¹
No cover	0	2,616
	90	7,935
	180	9,159
Red clover no-till	0	5,919
	90	9,118
	180	9,322
Red clover till	0	6,081
	90	8,298
	180	9,082
Nitrogen rate means within same cover LSD _{0.05}		2,334
Nitrogen rate means for different covers LSD _{0.05}		2,866

Table 12. Simple effects cover crop and nitrogen rate on corn grain yield at the Western Research Station in 2009.

Cover crop	Nitrogen rate, kg ha ⁻¹	Yield, kg ha ⁻¹
No cover	0	6,583
	90	11,532
	180	13,773
Red clover no-till	0	7,902
	90	12,683
	180	13,454
Red clover till	0	9,677
	90	13,142
	180	14,834
Nitrogen rate means within same cover crop LSD _{0.05}		841
Nitrogen rate means for different cover crops LSD _{0.05}		1,106

Figure. 1. Nitrogen response for the different cover crop treatments and the corresponding optimum N rate based upon quadratic regression at the Northwest Research Station in 2007.

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